# PECULIAR VELOCITIES IN THE A262 CLUSTER.

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**Abstract**

Distances of galaxies in the A262 cluster are obtained using the B, V and H-band Tully-Fisher relations. The derived range in distances ($\sim$ 60 Mpc) is much larger than the range in observed velocities ($\sim$ 2000 km s$^{-1}$). This suggests that large scale gravitational perturbations modify the velocity field of A262, a cluster belonging to the Perseus-Pisces supercluster, and produce peculiar velocities of the order of 2000 km s$^{-1}$. It is argued that the Perseus cluster can be identified as the origin of the observed perturbations.

**KEY WORDS**: Clusters: of Galaxies - Distance scale

## 1. Introduction

The cluster of galaxies A262 belongs to the narrow ridge connecting the main clusters in the Perseus-Pisces region, described by Haynes & Giovanelli (1986). A survey of the redshift space of these galaxies is available (Giovanelli & Haynes 1985a; Giovanelli et al. 1986, Haynes et al. 1988; Giovanelli & Haynes 1989) and identifies several peculiar features in the three-dimensional distribution of the galaxies. One of them is the very narrow velocity range in the ridge, between 4000 and 6000 km s$^{-1}$, for declinations north of $38^o$, with a remarkable lack of objects both foreground and background over an angular scale of $\sim$ 6 hours in Right Ascension, with the exception of the large velocity dispersion of the Perseus cluster (Fig. 2d in Haynes & Giovanelli 1986).

A262 represents a relatively isolated density enhancement in the main ridge, over an angular scale of $3^o$ (see Field 522 in Zwicky et al. 1961-1968). It appears elongated in the SW-NE direction with a relative gap of objects in a corona around it. As for the rest of the supercluster, A262 is also fairly isolated in the z direction (Haynes & Giovanelli 1986).

The direct use of redshifts as distance indicators would lead to the conclusion that galaxies in this region are distributed in a narrow range of distances. However, it is well known that, in the presence of gravitational perturbations, velocities are no longer reliable distance estimators. The simulation of the velocity distribution generated by a cluster potential well by Kaiser (1987) illustrates clearly that the velocity distribution is broadened at the cluster centers (giving rise to the 'fingers of God'), and is compressed at the outskirts. This latter phenomenon is due to the infall of surrounding galaxies towards the center of mass of the cluster. Could the narrow velocity distribution in the ridge of the Perseus-Pisces supercluster be also due to a perturbation? A distance indicator that is independent of redshift is therefore crucial to address this problem.

Methods based on the relation between internal galaxy dynamics and luminosity, such as the Tully-Fisher relation for spiral galaxies (Tully and Fisher 1977), and the Faber-Jackson or $D_n$-$\sigma$ relations for early types (Faber and Jackson 1976; Dressler et al. 1987), can be used to determine galaxy distances and compare them with measured velocities. The Tully-Fisher method in particular was used by Willick (1990) to map the distance of 320 spiral galaxies in the Perseus-Pisces supercluster. One of the results of his analysis is that galaxies in this region display peculiar velocities >2000 km $s^{-1}$, *i.e.* the velocity field is indeed highly perturbed, which supports the suspect that redshifts are not reliable distance indicators in this supercluster.

With the data that we have collected as part of the multifrequency study of galaxies in 9 clusters (see Gavazzi 1990; Gavazzi et al. 1990; Gavazzi et al. 1991a; Scodeggio et al. 1992), we can study the three dimensional distribution of galaxies in the region of the A262 cluster. The results for A262 have already been briefly discussed in a paper that addressed the Tully-Fisher distance determination, using the data for seven clusters (Gavazzi et al. 1991b, GSBT hereafter). Here we will expand the sample used and we will speculate on a possible interpretation of the peculiarities found in this region.

## 2. The Tully-Fisher distances and the Hubble flow

The velocity distribution of all the galaxies in A262 with measured redshift (72 out of 102 objects considered in this work) is plotted in Fig. 1. While broader than in the Perseus-Pisces ridge (Haynes & Giovanelli 1986) the velocity distribution is still fairly narrow, with a significant lack of objects in the foreground (V< 3000) and background (V> 6500). The mean cluster velocity, averaged over 71 galaxies (one object is clearly background, at $\sim$ 16000 km $s^{-1}$), is $\sim$ 4950 km $s^{-1}$, with a dispersion of 570 km $s^{-1}$.

Figure 1 also shows that the velocity distributions of the early and late morphological types appear to be different. The E+S0+S0a group shows a single peak at $\sim$4700 km $s^{-1}$, with a dispersion of 500 km $s^{-1}$, and with only 5 galaxies at V> 5100 km $s^{-1}$. On the contrary, spiral galaxies are roughly equally distributed between two peaks, at $\sim$4600 and at $\sim$5600 km $s^{-1}$. More quantitatively, statistical tests such as the Mann-Whitney U-test and Kolmogorov-Smirnov indicate a probability of $\sim 1.5$ and 4 % respectively that the two distributions are alike.

We have looked for relations between this dual velocity distribution and other spatial properties of the galaxies. We have found no evidence of subgrouping, or a different spatial distribution of the two velocity components on the plane of the sky. Therefore there seem to be two distributions of objects projected along the line of sight of A262, at two velocities $\sim 1000$ km s$^{-1}$ apart, one of which is mostly comprised of spiral galaxies.

To study the spatial properties in the third dimension, we have derived distances using the Tully-Fisher relation (TFr) in the V- and B-band (Tully & Fisher 1977) and in the H-band (Aaronson et al. 1979). We have used the photometrical data presented in Scodeggio et al. (1992) combined with the HI line width measurements taken from Giovanelli et al. (1982), Giovanelli & Haynes (1985b) and Scodeggio & Gavazzi (1992). A detailed derivation of the TFr parameters, with a comprehensive discussion on the estimated errors on the Tully-Fisher distances (TFD) can be found in GSBT, where the data of 7 clusters (A262 included) are used. In what follows we will use the GSBT results on the TFr and apply them to the A262 galaxies. $H_o = 90$ km s$^{-1}$ Mpc$^{-1}$ will be adopted (from GSBT).

TFD had been already derived for 14 objects, with $i > 45^o$ (GSBT). Here we have loosened the criteria for inclusion in the Tully-Fisher relation, and have calculated the TFD also for galaxies with $27^o < i < 45^o$ using the prescriptions of GSBT, for a total of 22 objects (Fig. 2). Since the TFD of these objects are distributed within the spread defined by the sample selected with more stringent criteria (cf. Fig. 4c of GSBT and Fig. 2), we can include them in this work to increase the statistics.

As already noticed by GSBT, the distribution of TFD is broader than expected for galaxies in a pure Hubble flow, and significantly larger than the estimated uncertainty in the TFD. It is also evident that the range spanned by the TFD parameter is much larger than the velocity range, which in this representation appears almost exclusively bimodal. Moreover, this bimodal velocity distribution does not correspond to a bimodal distance distribution: the average distance in both clouds is the same, $\sim 64$ Mpc, although with a large spread. The two clouds therefore are not spatially distinct.

A possible interpretation of the peculiar elongation in the TFD parameter with respect to the relatively narrow velocity dispersion in each of the two clouds (and even considering both together) is that the velocities of galaxies in the foreground and background of A262 are perturbed by the mass of A262 and are accelerated/decelerated with respect to the Hubble flow. This would not explain however why there are two velocity clouds, if they will be proven to be really distinct with more statistics.

The observed deviations from the Hubble flow however can be of $\delta$v $>$ 3000 km s$^{-1}$ at the extremes, and would therefore imply, if due to a gravitational pull from some mass concentration, a very large mass, inconsistent with the expected gravitational mass of A262. From the virial theorem we estimate M $\sim 2\times10^{14}$ $M_\odot$ for a velocity dispersion $\sigma \sim 500$ km s$^{-1}$. The mass required to perturb the Hubble flow expansion can be calculated from $\delta v/v = \Omega^{0.6}/3 \times \delta\rho/\rho$, valid in a spherical geometry for density enhancements over the mean density of the universe $\delta\rho/\rho \approx 1$ (Davis & Peebles 1983). With the exception of the extreme galaxies, peculiar velocities are on average $\delta v/v \sim 0.25 - 0.3$, which give $\delta\rho/\rho \sim$ 1-1.25. The mass derived from these density enhancements depends strongly on the volume considered. For a first order estimate of the parameters, we have considered a galaxy with an average $\delta v/v \sim 0.25$, at a distance TFD=85 Mpc, hence at d$\sim$ 35 Mpc from the cluster center (here we assume that A262 is in Hubble flow, therefore $d_{A262} \sim 50$ Mpc). The excess mass therefore is $\sim 3\times10^{16}\ \Omega^{0.4}$ $M_\odot$, a factor $\sim$ 100 higher than the virial mass of A262, even with the most favorable assumptions for $\Omega$.

Given the large discrepancy in the mass estimates, to discard any possible problem due to not optimal data, we have re-examined critically the data set that we have used. We have considered only those galaxies for which: a) $i > 60^o$, to ensure minimal error on the correction of the HI widths; b) only *best* quality HI data, *e.g.* those for which the line profile is significantly above the noise, and is clearly two-horned, as expected from a single object; c) objects isolated on the plane of the sky so that the $3'.2$ beam of Arecibo would not include any other galaxy, to further avoid confusion; d) objects for which the TFD derived in the V, B and H bands are within 10% of each other, to ensure that errors in the magnitudes would not affect the results.

Objects satisfying the above requirements are identified in Fig. 2. It is clear that while only 6 are left, the extreme distances are still present. We have then calculated what error on the magnitudes we should have made even on these cleaned data, to induce such a large scatter. We notice that, since the deviations are both above and below the Hubble flow, we cannot explain them with a systematic error, such as a wrong galactic extinction law, or a wrong application of the inclination corrections (galaxies are of roughly the same inclination $i > 60^o$), since those would only rigidly shift the distance scale, and would not reduce the scatter. To bring all the points within the cone of estimated uncertainties, we should multiply or divide each distance by a factor of $\gtrsim$ 1.2. This would imply an error of $\gtrsim$ 0.4 mag in the observations, inconsistent with the quality of the data (see Scodeggio et al. 1992) and condition d) above.

Supporting, although not conclusive, evidence of the distance range of spiral galaxies is given by the distribution of hydrogen deficient objects in this region. Hydrogen deficiency can be used as a tracer of the interaction between galaxies and the intracluster medium. A262 contains highly deficient (HIdef$>$ 0.5) spirals within a 1 Mpc projected distance from the cluster center (Giovanelli et al. 1982; Giovanelli & Haynes 1985b). The distribution of the deficiency parameter versus TFD shows that the objects at either very small or very large distances have normal HI content, while the few deficient objects for which TFD can be determined are at intermediate distances, consistent with that of the cluster. This suggests that the former have not crossed the cluster center yet. However, caution should be used, since we can only measure TFD for galaxies with *some* hydrogen, and we therefore have no estimate of the real spatial distribution of the extremely deficient objects (because they lack neutral hydrogen they cannot be included in the Tully-Fisher relation).

To further investigate the distance range, we have incorporated in the analysis the results for the $log\ D_n - \sigma$ relation, used to determine the distances of elliptical galaxies independent of their redshift (Faber et al. 1989; and references therein). We have used the data given by Faber et al. for 6 galaxies in the A262 cluster to derive their distance $d = R_e/90$ (from their Table 3). While five out of the six objects are consistent with the 'Hubble flow', one - NGC 708 - is at 86 Mpc. We notice that the centroid of the x-ray emission coincides with this galaxy (Magri et al. 1988), which should therefore lie at the bottom of the cluster potential well. While not conclusive, the $logD_n - \sigma$ distances are consistent with the TFD, and indicate that there might be deviations from the Hubble flow even in the 'virialized component' of A262.

We are aware of the paucity of data and of the need to better understand the observational data, the possible bias in the observed quantities and the validity of the methods to determine distances. Moreover, we have considered only a small fraction of a very complex region, and we are most likely undersampling the true three-dimensional distribution of the objects in the Perseus-Pisces region. Bearing in mind all these cautions, in the reminder of the discussion we will speculate on a possible scenario that emerges from the available data.

A262 is relatively close to the Perseus cluster (A426, at an angular distance of $17^o$), which is at a similar mean recessional velocity and is a much more massive object, with a virial mass $M \sim 2 \times 10^{15}$ $M_\odot$ (for a velocity dispersion $\sigma \sim 1300$ km s$^{-1}$). The working hypothesis will be therefore that the distance-velocity distribution of the A262 galaxies is modified by a gravitational field, centered at the Perseus cluster. We will further assume that the average distance of A426 and A262 is the same, at 60 Mpc, so that their linear separation is $\sim$17 Mpc.

To calculate the mass required to explain the observed deviations from the Hubble flow due to a spherically symmetric potential well centered at Perseus, we use the same test galaxy at TFD=85 Mpc and $\delta v/v \sim 0.25$. The resulting mass is $M \sim 2 \times 10^{16}$ $\Omega^{0.4}$ $M_\odot$, well above the virialized mass. To reconcile the two estimates, most of the mass should be outside of the Perseus cluster.

A second difficulty with this large mass is the lack of strong velocity dispersions in the Perseus ridge. In fact, as shown by Tully & Shaya (1984), in the presence of a gravitational field the velocity-distance diagram of galaxies in Hubble flow is modified to an S shaped curve, with the specifics of the S depending on the viewing angle for a given mass and time. Even with the relatively small mass model suitable to the Virgo cluster data, the velocity dispersion expected at small viewing angles is $\sim 1000$ km s$^{-1}$. The substantially larger mass estimated in this case would produce even larger perturbations, inconsistent with the velocity field observed at any given point in the ridge, with the exception of the Perseus cluster itself (Haynes & Giovanelli 1986).

We notice, however, that spherical geometry is hardly a good representation of the distribution of the luminous mass in this region even on the plane of the sky. Most of the galaxies in the ridge are within $\sim 6^o$ perpendicular to the direction of the ridge, *i.e.* $\sim 6$ Mpc (see Haynes & Giovanelli 1986). If we assume a more realistic geometry of a flattened spheroid, the gravitational pull in the spheroidal disk would be amplified with respect to the spherical model, and produce a peculiar velocity $\sim$ 2.4 times larger (Davis & Peebles 1983). At the same time the mass requirement is lowered by the ratio of the two volumes considered, which, in the assumptions above, is a factor of $\sim$ 7. The mass required would therefore become consistent with the virial mass of A426.

We could therefore explain the peculiar velocity-distance diagram for the galaxies in the A262 region with a gravitational perturbation from the Perseus cluster. As a consequence we expect to be able to observe similar peculiarities in the whole region, as indeed seen by Willick (1990), who analyzed the TFD vs velocity relation for 320 galaxies distributed in the whole supercluster, observed with a CCD in the R band. Independently, we have done a preliminary check on objects in the ridge between A262 and A426 using data from the literature. The TFD of these objects are derived from the corrected Zwicky magnitudes and from the line widths taken from Haynes et al. (1988) and from Magri et al. (1988), with the only constraints that the HI line profile be of *best quality* and the galaxy inclination $i>45^o$. The TFD vs velocity relation for these objects is plotted in Fig. 3. Although some of the spread could be due to the poorer quality of the photometrical data, the deviations from the Hubble flows are large also for these more isolated objects. Furthermore, Dressler et al. (1987) notice that, in their sample of elliptical galaxies, some objects in Perseus have peculiar distances. While some of the discrepancies could simply be due to unrelated foreground objects, others might be indicative of peculiar velocities of $> 3000$ km s$^{-1}$. The authors suggest that data problems might be the cause of these discrepancies, however in light of the present results these might instead be real.

It is clear that a more detailed model of the gravitational field in the Perseus-Pisces supercluster is needed. However, unless these methods of determining distances independent of redshift suffer from unknown biases, such as environmental dependencies, all of the above results indicate large deviations from the Hubble flow in this region, which could be explained with a gravitational perturbation due to the Perseus cluster.

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Figure Captions

**Fig. 1.** Velocity distributions for the A262 galaxies, separately for the early and late type objects

**Fig. 2.** TFD plotted as a function of heliocentric recessional velocity corrected for virgocentric infall. Galaxies with $i > 27^o$, and good quality HI spectra are included. Also a few galaxies with $i > 45^o$ that were not included in GSBT have been added: 522014, classified S0a; 522063 for which the V mag is derived from the J mag. 522073 and 522023 for which new photometry from Kitt Peak is available (see Tab. 3 in Scodeggio et al. 1992). Since 522023 and 522023S could not be resolved in the HI data, we have plotted it twice in the figure, for each optical mag., although the HI line is most likely coming from one of them only. The solid line indicates $H_o$=90 Km $s^{-1}$ $Mpc^{-1}$ (the mean value found by GSBT in 7 clusters) and the cone delimited by the dashed lines indicates 20% uncertainty in the distance determination, derived in GSBT. Galaxies with *best quality* data are identified (see text)

**Fig. 3.** Same as Fig. 2, also including galaxies in the ridge between A262 and A426